SUMMARY OF THE DISCUSSIONS ON STRUCTURAL DESIGN TECHNOLOGY

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT, PARIS, FRANCE

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by

R.B.Baird

NORTH ATLANTIC TREATY ORGANIZATION

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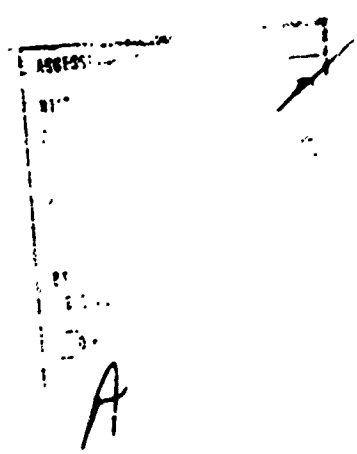
PREFACE

During the 40th Meeting of the Structures and Materials Panel in Brussels, a Conference was held on Structural Design Technology. The second day of this conference, which was chaired by Dr. James W.Mar, was devoted to a general discussion on various aspects of the structural design process. At the 41st Meeting in Ankara, Turkey, and the 42nd Meeting in Ottawa, Canada, discussions were continued on the specific topic of Structural Design Requirements. The present report, which was prepared by Mr. Richard B Baird, gives an evaluation of these discussions.

Undoubtedly the conference and ensuing discussions on Structural Design Technology have been very fruitful and will greatly help the Panel to define and channel its work in areas of direct practical need and concern.

J.B. de JONGE
Chairman
Structures Group



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SUMMARY

This paper presents the results of the discussions held during the 40th through the 42nd meeting of the Structures and Materials Panel (SMP) by the Structures Design Technology Group. The objective of the Group was to discuss design problems and questions created by new structures technology, guide future SMP activities towards the solution of those problems, and identify promising cooperative efforts to be accomplished within the NATO community.

At the 40th Meeting in Brussels, Belgium, eight papers were presented the first day and the second day was devoted to detailed discussion. AGARD Conference Proceedings No.184 contain the prepared papers and prepared discussions. Second day discussions concentrated in the areas of Materials, Fatigue and Fracture, Computer Aided and Optimum Design, and Aeroelasticity and Loads.

During the 41st Meeting in Ankara, Turkey, a paper was presented on the US Air Force Philosophy and Approach to Structures Safety, Durability, and Life Management. General discussion followed the presentation and due to the interest created by the paper, it was agreed to continue the discussion during the 42nd meeting in Ottawa, Canada.

Written discussion was presented at the 42nd Meeting in Ottawa, Canada, by representatives from France and the UK on the paper given in Ankara by the US Air Force. It was apparent that the European Community is hesitant about accepting the new specification without additional discussion, data, and understanding. The majority of concern centered around the safety design philosophy (safe life versus fail safe), the use of proof tests for structural demonstration, and the duration of the fatigue test.

It is apparent that the Structures Design Technology Group fulfilled, in all respects, the goals that were initially established. The technologies that are the basis for the majority of concerns expressed during the total life of the Group are Composite Structures, Fracture Mechanics, NDI, and the new USAF Safety Design philosophy. It is recommended that a cooperative program be established in the SMP to gather, analyze, and disseminate existing crack propagation data for various structures fabricated from conventional and composite materials. Final output would be a source of data for the structural designer.

INTRODUCTION AND DISCUSSION

The primary objective of the Structural Design Technology Group was to provide an opportunity for the specialists of the Structures and Materials Panel (SMP) to discuss the design problems and questions created by new technology. In this manner the SMP could guide future activities towards the solution of the most pressing problems and stimulate the initiation of cooperative efforts within the NATO Community. There is no doubt that the subject of structural design creates an atmosphere that is conducive to discussion. Not only was the discussion learned and interesting but it was also quite lively at times. This paper will attempt to summarize those discussions and provide this author's assessment as to future courses of action for the SMP in the structural design area.

During the 40th Meeting of SMP (held at the Societe Royale Belge des Ingénieurs et des Industriels, Brussels, Belgium, 11 - 17 April 1975) two days were devoted to Structural Design Technology. During the first day, eight papers were presented by experienced structural designers and the second day was devoted to detailed discussions. AGARD Conference Proceedings No.184 contains both the prepared papers and the prepared discussions that were presented on the first day. During the next day, a total of 27 discussers had been invited to the meeting to consider

the areas of new materials, fatigue and fracture, computer aided/optimum design, and aeroelasticity and loads. The significant results of those discussions follows:

New Materials

This subject received the majority of discussion and there were many thoughts offered on new materials and their application to aeronautical systems. Of course, all discussion was offered in the hope that service failures can one day be successfully eliminated. The salient points can be generally grouped into the areas of specifications, procurement of materials, material properties, and service testing.

There was general agreement among the US Contractors present (namely the Boeing Co., Wichita, Kansas and McDonnell Douglas, St Louis, Missouri) that specifications for new material procurement are very important and new specifications, properly prepared, will help solve existing problems. It was also pointed out however that these new specifications will not be successful unless the industry can gain access to the metal producer's plant to make sure the material processes are not changed. The creation of specifications for composite materials is of utmost importance and will require a great deal of effort and research. Composite materials are new and they will require a new approach to preparation of specifications. There was considerable discussion on the procurement of new materials and the problems that are associated with the material vendors. It is very important to control vendors on fracture toughness and this will undoubtedly lead to the requirement for many more lots of material for testing. There is evidence that failure in titanium parts can be directly attributed to the introduction of yttria in the material by the vendor. Control of vendors is of utmost importance and can eliminate a lot of problems that currently exist. (The statement relative to introduction of yttria in titanium is not intended to give the impression that in all cases this process is bad. There is also evidence which shows this process can be beneficial if done properly.)

Material properties and service testing of new materials is an area that has received much attention in the past and will continue to receive much attention. Data are required on fracture toughness and the variation of this parameter with different lots of material. In the area of composite materials, there is a great need for extensive service testing. Since composite materials are brittle, in-service damage can cause severe problems. In addition, the influence of environmental effects on the properties of composite materials is also an important area that needs investigation. The discussion on new materials essentially verified a number of things that the members of the SMP have known for a long time. New materials are difficult to introduce into service, and in a number of cases we really are concerned with improved old materials, not new materials. Composites, of course, fall into the category of truly new materials.

Fatigue and Fracture

The problems of fatigue and fracture are fundamental and the proper use of design techniques can contribute a great deal to the solution of these type problems. Fatigue analysis should be done the same way as stress analysis. It also seems desirable to combine the fatigue and stress groups into one group. Every part that is strength checked should also be fatigue checked.

The discussion then centered around the subject of scatter factor and the difference in philosophy that exists on this subject. A great many comments were offered on the new US specifications on durability and life and it is apparent that this is a subject for extensive discussion and debate.

Other subjects that received much attention included minimum crack lengths for design inspection intervals, influence of component thickness on initial flaw size, and manufacturing methods.

It is apparent that the subject of fatigue and fracture is of extreme interest to the members of the discussion group and it is a subject that will create controversy for a long period of time. The SMP can accomplish a great deal to resolve some of these differences and it is obvious this subject offers many challenging problems.

Computer Aided and Optimum Design

The computer and its use for structural design offers the opportunity to achieve optimum design at minimum cost. The computer also produces some problems that were not in existence during the days of manual structural design. There is a real danger that the stressman will lose his feel for the real problem when computer aided design is utilized. The stressman will have problems interpreting computer results and using those results to assess and visualize structural behavior. The design, of course, should be optimized for cost, weight, and combinations thereof. It is also very difficult to get actual cost data and these type data may be more available if normalized. There was some discussion on the belief that the computer may eventually produce engineering drawings. There was no doubt that the computer has revolutionized structural design and manufacture.

Aeroelasticity and Loads

This subject did not receive a great deal of attention although a few interesting thoughts and experiences were discussed. There was a strong feeling that the aeroelastic specialist should prepare rough rules and collect sufficient data before starting on the detailed aeroelastic analysis.

On the subject of loads, an interesting experience was related that quite clearly illustrates the problems associated with load predictions. A pilot yawed his airplane to clean the windscreen and this relative simple manouver created loads on the airplane that were approximately 100 times as damaging as the design conditions. A good illustration of the problem possible without accurate knowledge of the full load spectrum.

This day of discussion was of great benefit to both the participants and the audience. A number of future activities for AGARD were also identified. These activities were: (1) a working group for the collection and normalization of cost data for use in computer aided optimum design programs; (2) working group on computer aided design and computer aided manufacturing; and (3) a group to study the variations of structural safety factor with type of airplane and probability of load occurrence. No decisions were made on whether these activities should be pursued. It was concluded, however, that the Structural Design Conference should be continued until the Ankara meeting and this would then allow all participants time to digest the results of this conference.

During the 41st Meeting of the SMP (held at the Middle East Technical University, Ankara, Turkey, 28 Sep – 3 Oct 1975) the subject of Structural Design Technolcgy was further pursued when Col. M.Coffin of the US Air Force, presented a paper titled, "The Air Force Philosophy and Approach to Structures Safety, Durability, and Life Management". This paper discussed a new approach to structural integrity and as anticipated was well received and stimulated a good deal of discussion. This new approach to structural safety and durability will be summarized to some extent later in this paper.

The overall discussions on Col. Coffin's paper did not concentrate on any specific area but rather consisted of a question and answer period which explored many interesting areas and produced a great deal of "food for thought". Since this Air Force philosophy represents a great change from the normal way of verifying structural integrity, there seemed to be a general feeling of caution among the discussers, and international adoption of this new philosophy will take time. In addition to this overall trend in the discussion the following specific areas were also discussed.

The Germans have been trying for approximately 10 years to develop an approach such as this and in that respect they were glad to see such a specification in preparation. It was felt that this paper illustrated that the SMP is on the right track. Simulation of chemical environment during the fatigue test was discussed and it was pointed out that this is a difficult problem and in all probability would be simulated only during structural component tests.

There was concern expressed by the French that corrosion between parts would escape detection during the inspection phase and therefore simulation of the chemical environment during test was very important. It was generally agreed that this problem would have to be properly addressed, and it was the intent to include such considerations during the fatigue test. The UK also pointed out that it had been their experience, in one case, where they applied a potting compound during assembly of parts and 20 years later a teardown inspection revealed no corrosion. The point made was that proper design procedure prevents corrosion.

The new philosophy was summarized as follows:

1. Think economic life not fatigue life.
2. Experience drives designers to tougher materials, low stress levels, less emphasis on S/N design.
3. Durability tests cannot be unsuccessful.
4. Within industry, interpretation of new specifications is very important and you need the right kind of people to make the right interpretation.

The determination of design service life was an area of interest. Particular attention was paid to "who establishes the life and can it be changed?" The new specification states that the operational command and HQ USAF will establish the design service life. The general philosophy is that the establishment of design service life should not be an engineering decision but rather an operator's decision. Concern was expressed over this approach.

The subject of proof testing received a considerable amount of attention. The general consensus was that proof testing was a good approach as long as the loads could be determined with accuracy and the test setup was not too complex. There was a feeling of caution, however, that the proof test may be used in lieu of the static ultimate test to reduce development costs.

There are a number of assumptions that must be considered if the new philosophy on structural integrity is going to be successful. The approach is mathematically correct but one must also know the loads and stress levels. Assembly stresses could change the results and also influence the selection of sensitive areas. Other parameters, such as change in material properties, crack size variation caused by assembly procedures, and use of aircraft more than planned useage all influence the final results. Concern was expressed that the new specification does not account for all of these considerations. Although statements were made by the USAF representative that the new approach will address these types of variables, no real data were provided to substantiate such claims.

Discussion then centered around scatter factor and the number of lifetimes the airframe is tested during the fatigue test. The new Air Force specification will permit testing to only 2 lifetimes or the economic life. (Note, this allows fatigue testing to only 1 lifetime if the economic life is only 1 lifetime.) Previous experience by various companies has shown that a lot of intrinsic cracks are introduced into the structure during manufacture. Although a lot of effort had been devoted to cleaning up holes to prevent crack initiation, a great many "hot spots" were uncovered during full scale fatigue tests that were accomplished to scatter factors in excess of 4. The new specification is based upon the assumption that the actual airframe life in operation will be the same as the test life.

The Structural Design Technology Group was continued during the 42nd Meeting of the SMP which was held at the Government Conference Center, Ottawa, Canada, 4- 9 April 1976. Representatives from France and the UK provided prepared written discussion on the new USAF safety and durability specification as presented by Col. Coffin during the Ankara meeting. Additional discussion was also provided from the floor Since the new specification has many different design philosophies and policies that were addressed during the discussion, Table 1 has been prepared to provide some semblance of order to a very complex subject.

A number of conclusions may be drawn from those data shown in Table 1. There was general agreement that the determination of the design service life of the aircraft by the user is a relatively non-controversial requirement. It was further agreed that the design should be based upon planned usage. In this regard it was felt that the design spectrum should be updated by use of flight loads data. There was also general agreement relative to the selection of the fatigue test article, the fatigue test spectrum, the environment used during the test, and the inspection procedure accomplished during the fatigue test. With regard to the static test, it was thought that the accomplishment of a destruction test was well worth the increased costs.

It is also apparent that the European community is hesitant to accept the new USAF structural specification without additional discussion, data, and understanding. The majority of the concern is centered around the safety design philosophy, the use of proof tests, and the duration of the fatigue tests. A brief summary of these points follows.

The debate over safe life versus fail safe continues and the new USAF specification doesn't contribute much to the resolution of this problem. There is a feeling of caution with regard to the complete and abrupt abandonment of the safe life approach for the fail safe approach. Very valid and thought provoking questions were raised about such subjects as multiple cracking, limited data base for crack propagation behavior, uninspectable areas, acceptance of flawed structures instead of better quality structures, initial flaw sizes, flaws from accidental and battle damage, and lack of a universally accepted method to predict crack propagation rates. These kinds of questions are very difficult to answer.

There is strong feeling that the proof test should not be used to demonstrate strength and its worth as a general method of inspection is also questioned The point was made that the application of high loads during the proof test could cause subsequent adverse structural integrity problems. The proof test seemed to be acceptable only for checking the functioning of control systems.

There is no doubt that scatter factor or fatigue test duration is a subject that stimulates much debate and discussion and results in disagreement. This is really not surprising because, after all, the scatter factor is really an ignorance factor, and it is difficult to get people to agree on their degree of ignorance It is obvious however, that there is concern that a scatter factor of 2 is not sufficient. This author would like to point out that the new USAF specification would allow a scatter factor of only one (1) if the situation occurs where the economic life is equal to one (1) lifetime. This particular point was not discussed but it undoubtedly would have been an interesting departure from the norm.

With regard to the total duration of the fatigue test there seemed to be a general concensus that the test should be continued as long as possible. The costs associated with this approach seemed to be minimal compared to the amount of knowledge to be gained.

The Structures Design Technology Group in all respects fulfilled the goals that were initially established. This endeavor provided a mechanism by which the SMP could consider, discuss, and debate the design problems and questions which have been created by the development of new structures technology The time allocated by the SMP during the 3 consecutive Panel meetings was well spent and worthwhile Unfortunately, no problems were solved and many new thoughts were offered that tend to make the design problem more confusing and complex. It is very difficult to summarize the predominate concerns and problems expressed by the various participants over the life of the Structures Design Technology Group In spite of the hazards associated with trying to summarize international opinions, the author will attempt to do so. It is hoped that any disagreements created by this endeavor are offered in the spirit of NATO.

The technologies that are the basis for the majority of concerns expressed by the various participants are Composite Structures, Fracture Mechanics, NDI, and the new USAF Safety Design Philosophy The development of extensive material property data, fracture data and stress analysis techniques for composite structure received

extensive attention. With regard to fracture mechanics, the lack of a substantial data base and universally accepted analysis method for crack propagation in structures of different materials was the primary reason for the concern expressed. Finally, the new safety design philosophy offered by the USAF intensified the debate with regard to safe life versus fail safe design and the proper scatter factor to use during test.

RECOMMENDATIONS

There are many areas that the SMP could pursue to help solve the pressing structural design problems created by new structures technology. It is logical to select an area that has some chance of success within a reasonable time, has a broad enough scope to permit multiple application, and is manageable from a technical viewpoint. The subject of safe life versus fail safe design does not fit these criteria and therefore would be a difficult subject for the SMP to pursue. The area of crack propagation data for structures of different materials and the fracture properties of composite structures does appear to be an endeavor that meets a portion of the above criteria. It is therefore recommended that a cooperative program be established in the SMP to gather, analyze, and disseminate existing crack propagation data for various structures fabricated from conventional and composite materials. The final output of the program could be the publication of an AGARD document which provides a source of data for the structural designer of the future. This will be an ambitious program that, if successful, will help to produce structures that have reliability at minimum cost. This is the ultimate goal for the structural designer and the user of the structure. It is believed that the SMP can provide a much needed contribution in this area.

TABLE 1

Comments on New USAF Structural Specification

Specification Subject	*Requirement*	*SMP Member and Observers Comments*		
		France[1]	*United Kingdom*[2]	*United Kingdom*[3]
1. Design Service Life	Specified for each system by user	– No Comment	– No Comment	– No Comment
2. Design Usage Spectrum	Based on planned usage	Should be updated by flight loads survey – All airplanes equipped with data recording systems.	– No Comment	– No Comment
3 Safety Design Philosophy	Damage Tolerant Design Fail safe or slow crack growth – Assumes initial flaws – Minimum residual strength Control of critical parts	– Does not consider case of multiple cracking – Multiple Cracking – Concern over limited data base on crack propagation – Very practical case – Cracks start at same time from a number of holes – Covered by adequate scatter factor & fatigue testing – Should not accept flawed structures – Try to get better quality structures.	– Definitions are very important – Fail safe & slow crack growths are the same as fail safe – Seem to concentrate on manufacturing defects – Ignores accidental and battle damage – No mention of multiple initiation of defects – Unwise to abandon, completely, safe life approach.	– Still must be concerned about safe life for uninspectable structures – Initial flaws should be regarded as "Equivalent flaws sizes rather than real ones". – Estimate of crack propagation rate – no universally valid method exists.
4. Durability Design Philosophy	Economic life greater than design service life	– Should not underestimate safety aspects	– Basic idea is good	– Welcome requirements that take a realistic view.
5. Proof Tests Strength Demonstration	Required if static ultimate test not performed	– Strongly against proof test as a strength demonstration test	– Proof test as static strength demonstration or for checking control functioning is acceptable	– Proof test should not be used on every aircraft as a general method of inspection.
Inspection	Allowed if conventional NDI not practical or cost effective		Application of high loads can affect subsequent structural integrity	

(Continued)

TABLE 1 (Continued)

	Specification Subject	*Requirement*	*SMP Member and Observers Comments*		
			France[1]	*United Kingdom*[2]	*United Kingdom*[3]
6	Static Ultimate and Failure Tests	Required except When design has been previously verified or When separate tests performed on critical structure When the procuring activity approves deletion* * Author's Note The old specification required HQ USAF approval for deletion of static test	Static test should be accomplished to destruction	No Comment	- Static test should be accomplished to ultimate - Agree ultimate static test can be eliminated when design has been previously verified
7	Selection of Fatigue Test Articles	Early RDT & E Aircraft Full aircraft or Major assemblies	Agree	No Comment	- Questions about the standard of the structures - Early test specimen may be unrepresentative
8	Fatigue Test Spectrum and Environment	Flight by flight load spectrum plus Temperature Chemical environment	Agree Should be updated by flight loads survey	No Comment	- No Comment
9	Fatigue Test In-Process Inspections	Consistent with Design	No Comment	No Comment	- No Comment
10	Fatigue Test Schedule	One Lifetime prior to DSARC III	No Comment	Practically impossible to meet this schedule when thermal cycling is applied Thermal cycling can increase test time by a factor of 5 or more	- No Comment
11	Fatigue Test Duration	Two Lifetimes or economic life with program decision for continuation # # Author's Note If the economic life is one lifetime then the test can be terminated at the end of one lifetime.	Scatter factor 2 is too small Test should continue beyond 2 lifetimes Increases in life and payload make additional testing well worth added cost.	No Comment	Fatigue test should be continued as long as possible

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